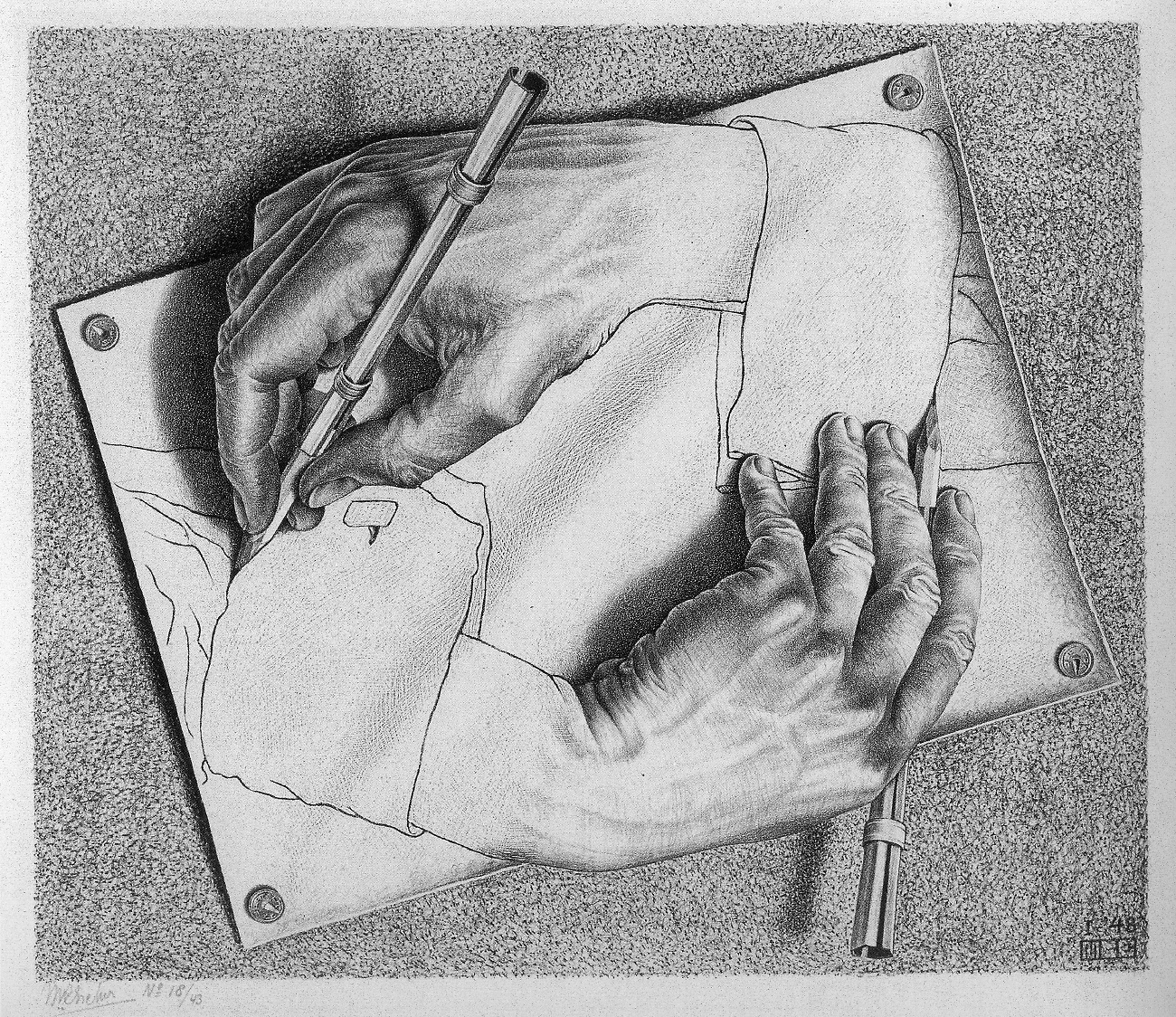
Electron-Ion Collider Detector Requirements and R&D Handbook

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**Contributors**

Many colleagues have made substantial and valuable contributions to this document and the studies it is based on. We especially want to thank …

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# Introduction

# Machine Parameters

## Beam Energies, Luminosities

## Rates and Multiplicity

## Interaction Region

# Detector Performance Requirements

## Physics Considerations for Detector Design

### Kinematics Overview

### The Extreme Forward Region: Roman Pots and Low Q2-Tagger

## Detector Goals

In the previous section we listed the requirements that can be derived from the key physics measurements at an EIC in terms of rapidity coverage, momentum reach, and electron, photon, and hadron identification. What evolves is a detector with the following key features:

* Hermetic coverage, close to 4π acceptance (pseudo-rapidity range up to +/-4)
* Low material budget on the level of 3-5% of X0/X for the central tracker region
* Tracking momentum resolution in few % range
* Reliable electron ID
* Good π/K/p separation in forward direction up to ~50 GeV/c
* High spatial resolution of primary vertex on the level of <20 microns

Other requirements can be derived from experiences at HERA and, to some degree, from LHC experiments. Table 2 summarizes all requirements as a function of pseudo-rapidity. They are essentially identical for JLEIC and eRHIC machine designs. How these requirements are met and with what potential technologies is subject of the next chapter.

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Table 2: Physics requirements for a an EIC detector.

# Technologies and R&D Needs

The majority of R&D in HEP and HENP is currently related to LHC phase-I (ALICE and LHCb) and phase-II upgrades (ATLAS, CMS). Here radiation hardness and high-rate capabilities are the top R&D priorities especially for pp collisions in the high-luminosity LHC era. Less emphasis is put on

PID with the notable exceptions of the LHCb RICH (and TORCH upgrade) systems. Several R&D efforts related to phase-I such as MAPS Si-Sensors, RICH PID, and GEM based TPC readouts have by now concluded since the detectors are now being constructed.

As illustrated in the previous sections many requirements for an EIC are unique and therefore demand R&D that is not covered by the current main stream HEP and HENP R&D efforts. In the following we discuss the possible technologies that could be deployed and to what extent R&D is necessary to make these technologies available for an EIC detector.

## Tracking Systems

### Central Tracking

#### Main Tracker

The tasks of the main tracker are (i) to allow for highly efficient track finding of charged particles scattered at central rapidities, (ii) precise determination of particle kinematics (momenta and scattering angles) and, to the extent particular technology allows, (iii) participation in lepton and hadron PID as well as (iv) providing rough timing information (optionally). Unlike the LHC detectors the tracker should have very small overall material budget, on the level of a few % of the radiation length. It should fulfil the basic requirements in terms of redundancy, in particular provide sufficient number of independent measurements per track (in the order of few to several dozens of space points as anticipated presently, although the detailed track finding efficiency studies have not been performed yet). Since the EIC physics community clearly expressed its interest in **two** independent general-purpose EIC detectors, the tracking R&D program should identify more than one viable technology for the main tracker. For various reasons, depending on the choice of a particular technology (long enough lever arm for track fitting, efficient multiple track separation, sufficient number of points for dE/dx measurement), but also because of the limited space inside an affordable (or readily available) solenoid magnet, a typical size of the main tracker is determined to be around 2 m in length and up to 80 cm in outer radius. The inner radius should be sufficient to accommodate the vertex detector. In case of an all-silicon main tracker vertex and main tracker are combined. The options considered so far are:

* (A) Medium size TPC: design either similar or identical to the sPHENIX central tracker. Moderate spatial resolution, somewhat compensated by the large number of independent measurement points for each track (sPHENIX design specs are 200-250 μm per space point and up to 40 points per track). If needed one can possibly improve both parameters significantly for an EIC application. For example, ILC R&D is targeted at obtaining better than 100 μm resolution per point in the whole volume, even for a much larger TPC; also one can most likely double the number of pad rows as long as the electronics costs are acceptable. Detector conveniently provides 3D points for tracking with no ambiguities, as well as a limited momentum range particle ID via dE/dx measurement. Calibration procedure however may be cumbersome, especially at higher luminosities in the presence of large space charge distortions due to the high ion back flow. Ion back flow can be reduced drastically by a proper choice of gas mixture and operating voltage, but typically at a cost of significant deterioration of the dE/dx resolution. This type of detector will suffer from a pile-up effects since the ionization produced by tracks from several bunch crossings is simultaneously present in the gas volume, due to the limited electron drift velocity (of an order of 30-80 μm/ns, which can result in a total drift time from the central membrane to the readout plane of up to ~30μs). This may or may not adversely affect track finding and track-to-event association procedures in the event reconstruction, given the relatively low charged track multiplicities of typical DIS events (of an order of one charged track per unit of pseudo-rapidity).
* (B) Straw tubes: design similar to the PANDA central tracker. High enough 1D spatial resolution in the radial-to-wire direction, typically better than 150 μm averaged over the tube volume, plagued however by the left-right ambiguity similar to the drift chambers. Spatial resolution in the direction along the wires can be provided by measuring time difference of signals arriving to both ends and is in general rather poor, in the order of ~1cm. Detector stacks of several layers can be designed with individual layers installed at small stereo angles to each other (few degrees), in order to provide the coarse coordinate measurement along the beam line also from the skewed UV-coordinate system. The adverse effect in this case is significant gaps between layers (so lower geometric efficiency) due to the fact that layer “container volumes” are no longer cylindrical but rather hyperbolic once the stack is glued together. Detector can be used with at least 1 bar over the atmospheric pressure (which means better dE/dx due to the higher ionization per track unit length). In the over-pressure mode the detector is self-supporting. Short drift length means the detector is in general fast and with appropriate electronics one can use cluster counting technique for improved dE/dx measurement.
* (C) Drift chamber: design similar to the ZEUS central tracker. Depending on the drift cell design (with the cells in general oriented along the beam line) the detector can have basic tracking properties similar to the straw tube tracker: decent 1D resolution and fast response, but poor resolution along the wires, and left-right ambiguity. Operational properties of the drift chamber solution are of a certain concern, since depending on the design details one broken wire may cause shutting down of a whole chamber segment.
* (D) All-silicon detector: design similar to the ILC SiD model detector central tracker or an earlier design of an ATLAS all-MAPS tracker. It seems the recent advances in the silicon detector technology may allow one to cover several square meters of surface with the thin high-resolution silicon sensors, at an affordable cost. Typically, one would consider a few concentric cylindrical surfaces, however more complicated configurations, partly integrated with the vertex, forward and backward silicon trackers must also be possible. Both 1D (strip) and 2D (pixel) configurations can be considered. Such a detector can provide decent spatial resolution down to few microns, as well as timing resolution as good as few dozens of picoseconds. Technically the picosecond level timing allows such detectors to provide – at least in theory – very reasonable PID for up to a few GeV/c momentum particles, even for very short, of an order of 1m, flight path. However, the trade-off between small pixel size, small sensor thickness, decent timing resolution and low power dissipation should be found, perhaps differently for the inner and the outer layers. Otherwise this solution would be the only one, which does not provide any (or very little) PID capability, even at very low momenta.
* (E) Micromegas tracker: design similar to the CLAS12 tracker. Several concentric micromegas cylinders composed of the “curved tile” building blocks cover all the radial space between ~20 cm and ~80 cm. Such a detector can provide decent 1D coordinate measurement of an order of ~100 μm in both tangential direction (C-layer) and along the beam line (Z-layer). It is anticipated that detector operation in the so-called micro-drift mode must be possible. This could provide short “tracklet” seeds for the track finder rather than “single point” measurements as well as improved dE/dx performance. The configuration with stereo layers must be possible as well but more R&D is required to prove this. This solution will also most likely provide less than 10 points per track. Vigorous R&D is also needed to explore the double side MPGDs option that would double the number of points per track at a minimum cost for material budget. The performance may suffer from the strong solenoid magnetic field. It is anticipated that detector operation in the so-called micro-drift mode must be possible. This could provide short “tracklet” seeds for the track finder rather than “single point” measurements as well as improved dE/dx performance. The performance may suffer from the strong solenoid magnetic field.

Depending on the details of the particular design the material budget of all these solutions can be sufficiently small, well below 10% radiation length. This may come at a cost of performance for options (B), (D) and (E), since in general both the tracker resolution and the material budget will scale with the number of layers. Reducing the number of tracking layers is only possible up to the point when track finding efficiency will start degrading, which is in particular true for the micromegas option and for the all-silicon tracker in case of 1D strip implementation.

One can seemingly achieve the required performance level in terms of momentum resolution with any of the options above, although the detailed Monte-Carlo studies have been performed only for the configurations (A), (D) and (E).

A slow “volume tracker” like a TPC can be complemented at the inner and the outer radius by few cylindrical Micro Pattern Gaseous Detector (MPGDs) layers for fast 2D tracking devices with spatial resolution better than 100µm, which would provide seed tracks correlated with the bunch crossing as well as serve the purpose of TPC calibration. Prime candidate technology for this would be cylindrical micromegas (see above), but the more modern RWELL option may be considered as well. Similarly, cylindrical MPGDs layers at the inner and the outer radius with the appropriate readout strip design can be added at the inner and outer radius if a Straw tubes or Drift chamber tracker to provide the submillimetre position resolution in the z direction along the beam axis.

#### Vertex/Silicon Tracker

The vertex tracker has to fulfil three tasks:

* Determine the vertex with the high precision (in conjunction with the forward-backwards silicon trackers).
* Allow the measurement of secondary vertices for heavy-flavour physics (e.g. F2, charm).
* Low-pT tracking, extending the range of the central tracker to tracks that curl up too much to be detected in the main tracker.

As pointed out in Table 2, the overall radiation length has to be kept at a minimum leaving few choices. Traditionally there has been a tradeoff in pixelated detectors among intrinsic spatial resolution, timing, read-out speed, and material thickness. Possible technologies are:

* Charged Coupled Devices (CCDs) offer demonstrated (e.g. SLD) spatial resolutions below 5μm and potentially very low material thickness since the active regions are w/o readout. Their disadvantages include slow readout and weak radiation hardness. R&D efforts were conducted within the ILC framework by the LCFI (Linear Collider Flavour Identification) Collaboration[[1]](#endnote-1) to work on these issues. While they achieved read-out times of 50 μs and a ladder thickness of ~0.1% X/X0 it appears that further efforts into CCD technology slowed down in the past years in favour of alternative technologies such as DEPFET and MAPS.
* DEPFET[[2]](#endnote-2) sensors (DEpleted P-channel FET) are being now used in BELLE-II[[3]](#endnote-3). The DEPFET is a field effect transistor with an additional implant underneath the channel and integrated on a fully depleted substrate. It combines the functions of a detector and the first amplification stage in one single device. The in-sensor amplification makes it possible to create very thin sensors with an excellent signal/noise ratio for minimum ionizing particles. Beam tests of prototype sensors by the BELLE-II9 collaboration showed a spatial resolution of 10 μm. The prototype sensors had a thickness of 50 μm, while the final sensors will be 75 μm thick.
* Most promising technology are likely Monolithic Active Pixel Sensors (MAPS) based on CMOS technology. MAPS were used in the STAR Heavy-Flavour tracker (HFT) and are the technology of choice for the new Inner Tracking System (ITS[[4]](#endnote-4)) and Muon Forward Tracker (MFT) of ALICE. With the ALPIDE (ALICE Pixel Detector) chip and the final stave and FPCB design used in the ITS, a total layer thicknesses of ~0.3 X/X0 can be reached for relatively short staves (up to 40cm or so, sufficient for a typical EIC detector barrel vertex tracker). The ALPIDE chip, developed by a collaboration formed by CCNU (Wuhan, China), CERN, INFN (Italy), and Yonsei (South Korea), contains a novel low-power in-pixel discriminator circuit that drives an in-matrix asynchronous address encoder circuit, read out by an end-of-column lossless data compression. The digitization of the signal within the pixel eliminates the need for an analogue column driver, reduces the power consumption significantly and allows for fast read-out. The ALPIDE chip features a 4 μs integration time, a power consumption of less than 39 mW/cm2, and an intrinsic spatial resolution of below 5 μm. Current alternatives to the ALPIDE chip are based on the MISTRAL, ASTRAL, and CHERWELL architecture.

While the ALICE ITS technology certainly comes close to the requirements, and the first realistic simulation results (full GEANT pass + Kalman filter track fit) are encouraging, further optimization of geometry (number of layers, radii, etc) has to take place when it comes to the actual design choices. The more detailed engineering and design of the central, as well as forward-backward tracker should clearly attract attention. When the EIC detector will be constructed the ALPIDE chip will certainly be outdated already. It is unclear to what extend MAPS R&D and E&D will progress in the future. MAPS development and optimization needs to be continued. The EIC would certainly benefit in improvements in the integration time[[5]](#footnote-1) as well as in a further reduction of the energy consumption and material budget going towards 0.1-0.2% radiation length per layer. Timing-wise the ultimate goal of this technology would be to time stamp the bunch crossings where the primary interaction occurred. This may impose different requirements depending on the machine design but is in general driven by the expected interaction rate at the highest luminosities. Concerning spatial resolution, the simulations indicate that a pixel size of 20 microns must be sufficient.

For efficiency and cost reasons it is desirable to use the same sensor chips for the central as well as for the forward-backward Si trackers. The required cooling system type depends strongly on the power consumption of the sensors. While the ALICE ITS will use a liquid cooling system, a further reduction of power consumption might allow for air cooling instead (similar to the ALICE MFT) thus reducing the material budget.

### Forwards and Backwards Tracking

Tracking detectors in the endcaps in general serve the purpose to complement the central tracker at the larger || where it typically does not provide sufficient number of hits, except probably for the all-silicon configuration. These detectors should cover moderately large surface areas behind the TPC endcap. Exceptionally high spatial resolution is not really required, although in order to help recover reasonably high momentum resolution at p≈30-50 GeV/c in the hadron-going direction the 50 μm spatial resolution per station is desirable.

It is also believed that in order to facilitate the reliable hadron PID in the forward gaseous RICH, a second set of large planar tracking detectors between the RICH volume and the electromagnetic calorimeter is desirable. Spatial resolution is not a concern here, but the detectors should cover the surface area of several square meters.

It is assumed that large area GEM and/or μRWELL detectors MPGDs (GEMs, MicroMegas, uRWELL) can be used for these purposes.

The obvious complication with the (very) forward and the (very) backward trackers is vanishing bending power of the solenoid magnet for the shallow scattering angles. As an example, at a pseudo-rapidity =3, which corresponds to roughly 100 mrad scattering angle, solenoid provides only 10% of its nominal maximum B∙dℓ integral in the bending plane. Therefore, one has to resort to using very thin detectors (in order to minimize the constant term in the momentum resolution expression) with very small pixel size (in order to minimize the slope in this same expression with the higher momenta).

MAPS technology is a natural choice, with all the benefits and all its drawbacks considered in detail in the previous section. It can be shown by direct Monte-Carlo modelling that 7-8 MAPS disks with 20 μm pixel size and 0.3% radiation length per layer installed between the nominal IP and roughly the TPC endcap location (1.0-1.2 m away from the IP) can provide the required momentum resolution in the whole pseudo-rapidity range and particle momentum range of interest for physics.

The alternative solution is a set of high-resolution GEM tracker stations installed up to the distances of ~3.0 m away from the IP. Monte-Carlo simulations show that this configuration should also work but would definitely require 50 μm or better spatial resolution per station.

Even if the MAPS disks are used for tracking at the very forward and very backward  one may want to complement them with the fast low-material budget trackers like Cr-GEM, the GEM detector variety with the copper layer removed from the foils.

### Roman Pots

One of the flagship measurements for an EIC is the measurement of the cross-section for Deeply Virtual Compton Scattering (DVCS) through the reaction channel ep -> ep. This is an important process because it gives access to the GPDs of gluons, allowing us to learn about their transverse spatial distribution inside the proton. One characteristic of these reactions is that the proton scatters at a very small angle and near beam energy. This makes it challenging to register these protons, which is a requirement to study this process, as it is necessary to verify that the proton remains intact and to ensure exclusivity of the measurement.

The expected distributions of the protons as a function of their polar scattering angle and momentum is shown in Figure 13 for collisions at different proton beam energies. Nearly all protons fall outside of the main detector acceptance. Specialized instrumentation is needed to measure the protons that scatter at such small angle. Various experiments at other facilities have implemented forward proton taggers as Roman Pots to access these protons. The Roman Pots need to be designed such that they can be retracted away from the beam during injection and moved towards the beam once stable conditions are achieved. This allows the detectors to be placed as close to the beam as possible, maximizing the acceptance to these protons.

The distance to the core of the beam to which the Roman Pots can be placed depends on the beam width at the location of the station. Previous experience is that the safe operating distance is roughly 10 of the beam width from the core of the beam. The Roman Pot location has to be carefully coordinated with the machine and magnet design group to ensure there is sufficient acceptance through the magnets, as well as sufficient dispersion to pull off-momentum protons out of the beam into the detectors and a small enough beam size at the location of the Roman Pots so that they can be placed as close as possible to the beam. Additional R&D efforts on sensor design are ongoing in regards to the development of "edgeless" sensors or sensors that can be tailored to the shape of the beam to further increase the acceptance to these small angles scattered protons.

Simulations have been performed to investigate the momentum range needed for a measurement of the DVCS process. This is summarized in Figure 15 below, which shows the expected uncertainty on the gluon impact parameter extracted from the measurement using 10 fb-1 of data and full acceptance over the |*t*| range indicated in the figure. Figure 15 shows the ideal case listed in the requirements. Figure 16 and Figure 17 demonstrate the negative effect of the acceptance truncation at either the lower or higher end of the stated |*t*| range, respectively.

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*Figure 15 (Left) A simulation of the measurement of DVCS cross section for 20x250 GeV e+p collisions representing statistics from 10 fb-1 of data. The measurement also assumes an acceptance range of 0.18 < pT < 1.3 GeV/c. The band represents the fit to the simulated data, along with its associated uncertainties. (Right) The translation of the cross-section measurement to the measurement of the structure function F2 with its associated uncertainties.*

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*Figure 16 Same as Figure 15, but for an acceptance range of 0.44 < pT < 1.3 GeV/c*

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*Figure 17 Same as Figure 15 but for an acceptance range of 0.18 < pT < 0.8 GeV/c*

Basic requirements on the Roman Pot systems based on simulations and knowledge from other facilities are summarized below:

1. Installed in a warm region of the IR.
2. ZDC detectors required to veto the nuclear breakup.
3. Proton acceptance in the range of 0.18 < pT < 1.3 GeV/c (0.03 < |t| < 1.7 GeV2).
4. Multiple stations to allow for efficient tracking, as well as greater acceptance over a wider range in |t|.
5. A momentum resolution comparable to that of currently achieved at STAR.

### Low-Q2 Tagger

Access to a wide range of the relevant kinematic variables are paramount to allow for a flexible physics program at the EIC. The focus of this section is on the available Q2 coverage at smaller values. The Q2 of an event can generally be reconstructed by measuring the angle and energy of the scattered electron in a DIS event (though there are other methods available that rely on the reconstruction of the hadronic final state). Figure 18 as well as Figure 19 show the distribution of the scattering angle of the electron and its momentum as it correlates to the Q2 of the event as simulated with PYTHIA for 20 GeV electrons colliding with 200 GeV protons. The distributions look similar for other collision energies. A strong correlation is observed. Most of the events at low Q2 (Q2 < 0.1 GeV2) result in the electron scattering at very small angle (less than 20 from the electron beam direction) with a momentum very close to the beam momentum. This implies that electrons from these events will be outside of the main detector acceptance and thus a dedicated device to measure these electrons is required.

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*Figure 18 A PYTHIA simulation of 20 GeV electrons colliding with 250 GeV protons displaying the correlation of the scattered electron angle with Q2.*

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*Figure 19 A PYTHIA simulation of 20 GeV electrons colliding with 250 GeV protons displaying the correlation of the scattered electron momentum with Q2.*

Such a device needs to be incorporated into the machine interaction region design to ensure that these electrons are sufficiently pulled away from the beam to register in the detectors. The detector needs to have good energy and position resolution as well in order to calculate the scattering angle of the electron and thus reconstruct the Q2 of the event. Additionally, it would be helpful for the detector to have a combination of tracking and electromagnetic calorimetry, which would assist in vetoing photons hitting the detector and help with electron identification.

## Calorimetry

* Crystal calorimeter
* SciFi
* Shashlik
* Other options (?)
* Light collection, including photon detector technology (SiPM, APD, ….)

### Electromagnetic Calorimeter

#### Barrel Calorimeter

#### Forwards and Backwards Calorimeter

### Hadron Calorimeter

### Zero Degree Calorimeter

## Particle ID

eRD14, eRD6, eRD22

* Modular RICH, dual radiator RICH
* DIRC and the like
* TRDs
* ToF
* Other

### Central Barrel PID

### Forwards and Backwards PID

## Luminosity Measurements

Essential to any physics program at an EIC is the precise measurements of the delivered luminosity, better than 1%. The measurement of the luminosity at the collision energies under consideration can be based on measuring bremsstrahlung photons from the *ep*-scattering, e + p -> e + p + . This is a well-known calculable QED process with a large cross-section making it a prime candidate to measure the luminosity. Additionally, the radiative corrections in the relevant energy range are small. This reaction produces photons that are emitted in a narrow cone around the direction of the incoming electron beam, and so the goal for this measurement is to measure photons in the very backward region. This can been seen in Figure 20, which plots the analytic calculation from QED for the differential cross section as a function of photon energy (left) and polar scattering angle (right) for different beam energy configurations.

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*Figure 20 The differential cross section for Bethe-Heitler scattering as a function of photon energy (left) and scattering angle (right). Different collision energies are shown by the color-coding and described in the legend.*

As can be observed in Figure20, photons from this process generally scatter at small angle, where the peak of the distribution is around 0.03 mrad. Thus, the spread of the cone of photons in the detector will be dominated by beam effects, such as the angular divergence that is typically a factor of 10 or so larger than that from direct physics process. The angular divergence quantifies the spread in the angle at which the collision occurs. Typically beams at the IP are squeezed to drive up the luminosity.

The luminosity is directly related to the number of detected photons as L = N / (A), where L is the luminosity, N is the number of detected photons, A is the acceptance correction for photons in the measured range, and  is the integrated cross-section in the measured range. Since the cross section is accurately known, the main sources of systematic uncertainty are on N, the number of photons that we measure coming directly from the elastic *ep*-scattering, and the acceptance correction.

The main requirement of the luminosity measuring system is to have sufficient acceptance through the machine to the detectors. This is not a trivial task and requires close collaboration with the machine designers. The detectors need to be fairly radiation hard because of to the large luminosity and high intensity of Bethe-Heitler photons. It is important to reduce synchrotron radiation flux hitting the detector. The detector also needs to be able to track the luminosity as a function of time, so that changes in luminosity over each fill can be accounted for.

## Trigger and Data Acquisition

* Streaming vs. triggered
* RO Electronics (what is needed what might exist)
* Where is R&D needed?

## Polarization Measurements

### Electron Beam

Systems need to be in place to quantify the polarization of the beam. Depending on the specifics of the electron beam of the machine, the polarization needs to be monitored as a function of time and per bunch. If one invests in an injection scheme that requires multiple cathodes to fill the machine, the polarization monitoring must be done for each individual cathode as a function of time. The natural option for electron beam polarization measurements at the energy and current of the beams under consideration is Compton scattering.

Under this method, circularly polarized laser light impinges upon the electron beam. The cross section of the Compton interaction depends on the polarization of the photon and electron. Since this is a pure QED process, it can be calculated analytically, giving a functional form for the asymmetry in the cross section between the polarization combinations in the collisions. The asymmetry can be measured by counting the photons produced with collisions with the different spin combinations, with the results being fit to the analytical expression for the asymmetry. The polarization is a fit parameter, and thus can be extracted from the measurement. The main requirement for such a measurement is to have a space for a Compton interaction point, where the laser hits the beam. This process must also be parasitic to the beam in that the measurement needs to have no effect on the beam. And the rate of collisions must be sufficiently high to obtain polarization measurements on the time scale of seconds or minutes. A high rate is also required to minimize systematic uncertainties to the sub-percent level.

### Proton Beam

### Light Ion Beams

# The EIC R&D Program

In January 2011 Brookhaven National Laboratory, in association with Jefferson Lab and the DOE Office of Nuclear Physics, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC. The primary goals of this program are to develop detector concepts and technologies that have particular importance for experiments in an EIC environment, and to help ensure that the techniques and resources for implementing these technologies are well established within the EIC user community. It is also anticipated that the topical detector-type-oriented “consortia” (calorimetry, tracking, PID and others) will partly form a basis of the active EIC community and later on participate in shaping up the actual EIC physics collaboration(s).

This program is supported through R&D funds provided to BNL by the DOE Office of Nuclear Physics. It is not intended to be specific to any proposed EIC site, and is open to all segments of the EIC community. Proposals should be aimed at optimizing detection capability to enhance the scientific reach of polarized electron-proton and electron-ion collisions up to center-of-mass energies of 50-200 GeV and e-p equivalent luminosities up to a few times 1034 cm-2s-1. Funded proposals are selected on the basis of peer review by a standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology and collider physics. This committee meets twice per year, to hear and evaluate new proposals, and to monitor progress of the ongoing projects. The program is administered by the BNL Physics Department. This program is funded at an annual level of $1.0M - $1.5M, subject to availability of funds from DOE NP.

The following projects were or are supported by the program:

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| ID | Topic | Status |
| RD 2011-1 | Fiber Sampling Calorimeters | Merged into eRD1 consortium |
| RD 2011-3 | DIRC -based PID | Merged into eRD14 consortium |
| RD 2011-5 | Radiation resistant Si PM | Concluded |
| RD 2011-6 | Tracking/PID/Simulation | Merged into eRD6 consortium |
| RD 2012-3 | Forward Tracking: GEM & Micromegas | Renamed into eRD3 |
| RD 2012-5 | Physics Simulations/Physics Event Generators | Concluded |
| RD 2012-8 | Crystal R&D for a forward calorimeter | Concluded |
| RD 2012-11 | Spin-light polarimeter | Concluded |
| RD 2012-12 | Forward RICH detector | Merged into eRD14 consortium |
| RD 2012-13 | Forward EM pre-shower | Concluded |
| RD 2012-14 | Tungsten fiber Calorimeters | Merged into eRD1 consortium |
| RD 2012-15 | GEM based TRD | Concluded |
| RD 2013-2 | Magnetic field cloaking device | Renamed to eRD2 |
| RD 2013-5 | 10 Picosecond TOF: MCP-PMTs | Merged into eRD14 consortium |
| RD 2013-6 | Polarimetry & luminosity monitor | Renamed to eRD12 |
| eRD1 | EIC Calorimeter Development | Calorimeter consortia, ongoing |
| eRD2 | A Compact Magnetic Field Cloaking Device | Concluded |
| eRD3 | Design and assembly of fast and  lightweight barrel and forward tracking  prototype systems for an EIC | Ongoing |
| eRD6 | Tracking/PID | Tracking consortium, ongoing |
| eRD12 | Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam | Concluded |
| eRD11 | RICH detector for the EIC’S forward region particle identification | Merged into eRD14, ongoing |
| eRD10 | R&D Proposal for (Sub) 10 Picosecond  Timing Detectors at the EIC | Merged into eRD14, ongoing |
| eRD14 | Proposal for an integrated program of Particle Identification (PID) challenges and opportunities for a future Electron Ion Collider (EIC) | PID consortium, ongoing |
| eRD15 | A proposal for Compton Electron Detector R&D | Ongoing |
| eRD16 | Forward/Backward Tracking at EIC using MAPS Detectors | Ongoing |
| eRD17 | DPMJetHybrid 2.0: A Tool to Refine  Detector Requirements for  eA Collisions in the Nuclear Shadowing/Saturation Regime | Ongoing |
| eRD18 | Precision Central Silicon Tracking & Vertexing for the EIC | Ongoing |
| eRD20 | Developing Simulation and Analysis Tools for the EIC | Ongoing |
| eRD21 | EIC Background Studies and the Impact on the IR and Detector design | Ongoing |
| eRD22 | GEM based Transition  Radiation Tracker R&D for EIC | Ongoing |

Proposals, progress reports, presentations, and the committee reports can be found on the following web site: https://wiki.bnl.gov/conferences/index.php/EIC\_R%25D

# References

1. <http://hepwww.rl.ac.uk/lcfi/> and document listed there. [↑](#endnote-ref-1)
2. *Sensors* **2016**, *16*(5), 608; doi:[10.3390/s16050608](http://dx.doi.org/10.3390/s16050608) [↑](#endnote-ref-2)
3. [Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment](http://www.sciencedirect.com/science/journal/01689002), [Volume 831](http://www.sciencedirect.com/science/journal/01689002/831/supp/C), 21 September 2016, Pages 85–87 [↑](#endnote-ref-3)
4. Technical Design Report for the Upgrade of the ALICE Inner Tracking System, J. Phys. G 41 (2014) 087002, <https://cds.cern.ch/record/1625842?ln=en>. [↑](#endnote-ref-4)
5. A luminosity of 1034 cm-2 s-1 will bring the interaction rate to 500kHz or 1/(2 μs). The ALPIDE chip features currently an integration time of 4 μs. [↑](#footnote-ref-1)